Journal of
Ceramic Science
and Technology

J. Ceram. Sci. Technol., **17** [1] 93-100 (2026)
DOI: 10.4416/JCST2025-00024
available online at: http://www.ceramic-science.com

Influence of Er: YAG Laser, and Radachlorin-Activated Low-Level Laser Therapy on the Contact Angle, Surface Topography, and Shear Bond Strength of Lithium Disilicate Ceramics and Resin-Based Ceramics

A. Barakat[1], S. AbdulRahman AlTowayan[2], N.H. Shaheen*[1], A.M. Elmarakby[1, 3], K.A. Rayes[1], M. Mahmood[1]

[1]Department of Restorative and Prosthetic Dental Sciences, College of Dentistry, Dar Al Uloom University, Riyadh 13313, Saudi Arabia.
[2]Assistant Professor in Restorative Dentistry, Department of Conservative Dental Sciences, College of Dentistry, Qassim University, Kingdom of Saudi Arabia.
[3]Department of Operative Dentistry, Faculty of Dental Medicine, Al Azhar University, Assiut Branch, Egypt.

received September 2, 2025; received in revised form September 15, 2025; accepted October 5, 2025

Abstract

To assess the influence of surface conditioners, i.e. hydrofluoric acid (HFA), Er: YAG laser, and Radachlorin-activated low-level laser therapy (LLLT), on the contact angle (CA), surface topography, and shear bond strength (SBS) of lithium disilicate ceramics (LDC) and resin-based ceramics (RBC). RBC Lava Ultimate (Group A) and IPS Emax (Group B) were used to obtain forty-five discs in each case. Each group was further divided into subgroups based on the conditioning protocol used. Group 1: HFA, Group 2: Er: YAG laser, and Group 3: LLLT (RD). CA (n = 2) and surface topography analysis (n = 3) were performed using a goniometer and scanning electron microscope. Resin cement was built on ten discs from each group, followed by the evaluation of the SBS by means of a universal testing apparatus. A one-way ANOVA and Tukey test were utilized to conduct a comparative analysis of CA and bond strength values. The lowest CA was exhibited by Group 1A (HFA + LDC) with the highest bond strength. Whereas Group 3B (RD-LLLT+RBC) presented the highest CA and lowest SBS. The Er: YAG laser can be considered as a suitable alternative to HFA for enhancing the contact angle and bond integrity of adhesive cement. LDC and RBC exhibited comparable contact angle and bond strength outcomes, except in the hydrofluoric acid group.

Keywords: Hydrofluoric acid, low-level laser, Radachlorin, bond strength, laser.

I. Introduction

In contemporary dentistry, the utilization of ceramic CAD/CAM blocks has seen a marked increase, driven by escalating aesthetic expectations [1]. The importance of material selection has intensified with the growing variety of CAD/CAM ceramic materials [2]. Lithium disilicate ceramics (LDC) are glass ceramics that are characterized by their composite-like nature, wherein the ceramic component functions as a reinforcing filler while the glassy phase serves as the foundational matrix [3]. Despite the enhancement of aesthetic attributes because of the glassy phase of glass ceramics, it concurrently imparts brittleness to the structure and has a propensity to abrade opposing dentition [4, 5].

In an endeavor to alleviate the limitations inherent to glass ceramics, the emergence of resin-impregnated ceramics has gained significant attention. Resin-based ceramics (RBC), which are categorized as particle-reinforced composites, consist of a polymeric matrix that integrates a minimum of 80 % nanoscale ceramic filler particles [6]. RBC offers numerous advantages over both glass ceramics and conventional ceramics, such as improved replication of dentin‘s elastic properties, superior polishability, the ability for intraoral repair, and the elimination of the need for firing [7]. Nonetheless, it remains undetermined which type of ceramic demonstrates superior performance in achieving optimal mechanical properties [8].

It is well acknowledged that surface pretreatment of ceramic restorations before cementation greatly improves the mechanical outcomes [9] Hydrofluoric acid (HFA) notably improves the surface morphology of LDC and RBC. The HFA etchant operates by dissolving the glass phase of the ceramic matrix, thereby revealing the underlying crystalline structure [10]. However, HFA possesses the potential to inflict severe damage to soft tissues due to its highly corrosive nature. Therefore, it is imperative to explore superior alternatives [11, 12].

* Corresponding author: nasser.s@dau.edu.sa

Lasers of different types have been used in dentistry for surface preconditioning of different ceramics. Erbium-doped yttrium aluminum garnet (Er: YAG) lasers are regarded as one of the most advanced categories of lasers because their wavelength matches the absorption peak of water [13]. Turker and coworkers estimated the SBS of RBC with resin cement after pretreatment with an Er: YAG laser and observed that it presented comparable bond strength outcomes to that of HFA [14]. Furthermore, Almutairi and associates revealed that Er: YAG laser treatment exhibited analogous outcomes for SBS to HFA in LDC [15]. However, there is still no comparative study available which has identified the influence of Er: YAG lasers on the contact angle (CA) and SBS of resin cement bonded to LDC and RBC.

In addition to traditional laser applications, low-level laser therapy (LLLT) in conjunction with photosensitizers (PS) has garnered considerable scholarly interest within the domain of dentistry. Among the diverse array of PS, Radachlorin (RD) is recognized as a second-generation photoactive dye which exhibits a pronounced absorption peak at 662 nm wavelength, thereby facilitating improved light permeation within the treated tissue when juxtaposed with first-generation PS [16, 17]. However, the efficacy of RD-mediated LLLT as a ceramic surface conditioner with regard to CA and SBS with resin cement has yet to be elucidated.

The current inquiry was founded on the assumption that there will not be a notable difference in the CA and SBS of RD-LLLT- and Er: YAG-laser-pretreated LDC and RBC discs in comparison to the HFA. Additionally, it was also expected that there would be no major disparity in the CA and bond integrity of adhesive cement to LDC and RBC across the same conditioning groups. The present study seeks to assess the influence of various surface conditioners on the CA and adhesive strength of LDC and RBC to resin cement.

II. Material and Methods

(1) Sample preparation

CAD/CAM restorative blocks, i.e. RBC Lava Ultimate (3 M ESPE, St. Paul, MN, USA), referred to as (Group A), and IPS e.max (Ivoclar Vivadent, Schaan, Liechtenstein), referred to as (Group B), were used to obtain forty-five discs from each group, each measuring 4 mm in diameter and 2 mm in thickness (n = 45). The sample size was calculated using G Power software [6, 18]. The sectioning of the block into discs was performed with the help of a slow-speed saw (Isomet 1000, Bursa, Turkey). Subsequently, the specimens were embedded in an auto-curing acrylic resin (Major. Base 20, Moncalieri, Italy). The discs underwent polishing using silicon carbide paper with grits of 600, 800, and 1 000, respectively. Each group was further divided into three subgroups based on the conditioning protocol used (n = 15) [6, 18]

Group 1: HFA 10 % HFA (Angelus, Londrina, Brazil) was used for conditioning samples for 1 min, followed by rinsing [19].

Group 2: Er: YAG laser: Er: YAG laser (Fotona, At Fidelis, Ljubljana, Slovenia) was used in a short-pulse mode, characterized by 2 940 nm wavelength, 2 W power, 200 MJ pulse energy, and 10 Hz frequency. The laser was applied in a sweeping motion at 8 mm from the LDC and RBC discs for 60 seconds. A contra-angle handpiece, with an air flow of 40 % and a water flow of 60 % was used for the irradiation [20].

Group 3: LLLT (RD): An RD solution was prepared by dissolving 0.35 % RD (Rada-Pharma Co, Ltd., Moscow, Russia) in saline. It was smeared on the discs and irradiated with a diode laser (Woodpecker LX16 Plus Dental Laser) operating at a wavelength of 662 nm utilizing a fiber optic tip. The parameters include a power output of 3 W and an energy density of 28 J/cm^2 in a continuous mode for 60 seconds [16].

All samples underwent ultrasonic cleaning (Pro-Sonic 600; Sultan Healthcare, USA) for 5 mins to remove contaminants and were then air-dried.

(2) CA assessment

The CA was measured on two discs from each group using the sessile drop technique with a goniometer (Ramé-Hart 100 – 00; Ramé-Hart Instrument Co) connected to a computer with specialized software (DSA3, V1.0.3 – 08, Kruss). At ambient temperature (± 24 °C), a single drop (11 µl) of distilled water was placed at the center of ceramic substrates using a needle. The CA was measured after a period of 5 seconds [21].

(3) Surface topography analysis

Three specimens from every category were coated with a layer of gold using a sputter coating device (Emitech/Quorum K500X, England) and examined under a scanning electron microscope (SEM) (JSM 610LA; JEOL Ltd) at an accelerating voltage of 30 kV and a magnification of 2000X [6, 22].

(4) Resin cement buildup (n = 10)

Self-adhesive dual-curing resin cement (Maxcem Elite Kerr Corp., USA) was built on ten ceramic surfaces using cylindrical polyethylene pipes measuring 4 mm in diameter and 3 mm in height. The cement was then photopolymerized using LED light (Elca Technologies, Imola, Italy) for 40 secs. The polyethylene tube was cut away with a scalpel. Afterwards, all the bonded samples were stored in distilled water at 37 °C for 24 hours.

(5) Artificial ageing

Samples were subjected to thermocycling (Schabach, Germany) by immersing in water baths maintained at a temperature ranging from 5 – 55 °C, with an immersion time of 30 seconds and a transfer time of 2 secs. A total of 10 000 cycles was completed [23, 24].

(6) SBS testing

A universal testing machine (UTM) (TSTM 02500; Elista Ltd. Sti, Istanbul, Turkey) was employed to conduct the SBS testing. The axial force was applied at the interface of resin and ceramic utilizing a uni-beveled chisel rod at a rate of 0.5 mm/min until the point of fracture. The bond strength was expressed in megapascals (MPa), which was estimated by dividing the failure force, expressed in Newtons, by the surface area (mm^2), in line with the subsequent formula:

$$\textbf{SBS = Force (N)/Area (mm}^2\textbf{).}$$

(7) Fracture pattern analysis

Specimens were evaluated under a stereomicroscope (Leica MZ6) at a magnification of 40X to ascertain the fracture type, which is categorized as adhesive, cohesive, and admixed [25].

(8) Statistical analysis

The data were analyzed utilizing the IBM SPSS V23 software programs. One-way ANOVA and post hoc Tukey tests were employed to compare CA and bond strength values. $P < 0.05$. Data normality was assessed using the Kolmogorov-Smirnov test

III. Results

(1) SEM assessment

SEM micrograph Fig. 1A) LDC subjected to Er Yag laser treatment reveals a loss of matrix with clearly visible glass particles. Fig. 1B) RBC exposed to Er: YAG laser displays particle fusion and resin melting, enhancing *Ra*. SEM image Fig. 1C illustrates LDC treated with RD-LLLT, showing no inter-glass matrix loss, and glass particles are not prominent. D) RBC treated with RD-LLLT exhibits no matrix loss, with a visible particle-reinforced composite.

(2) Contact angle assessment

The mean CA among the different tested groups is presented in Table 1. The lowest CA was identified in Group 1A (HFA + LDC) (8.77 ± 0.28). Whereas Group 3B (LLLT (RD) + RBC) presented the highest CA (38.39 ± 0.36). Comparison among different investigated groups revealed that Group 1A, Group 2A (Er: YAG laser + LDC) (8.99 ± 0.26), and Group 2B (Er: YAG laser + RBC) (9.12 ± 0.30) demonstrated comparable CA. ($p > 0.05$). Similarly, Group 3A (LLLT (RD) + LDC) (37.21 ± 0.32) and Group 3B also revealed no significant difference in their CA. ($p > 0.05$). On the contrary, Group 1B (HFA + RBC) (20.43 ± 0.10) displayed significantly different CA values than all other tested groups. ($p < 0.05$)

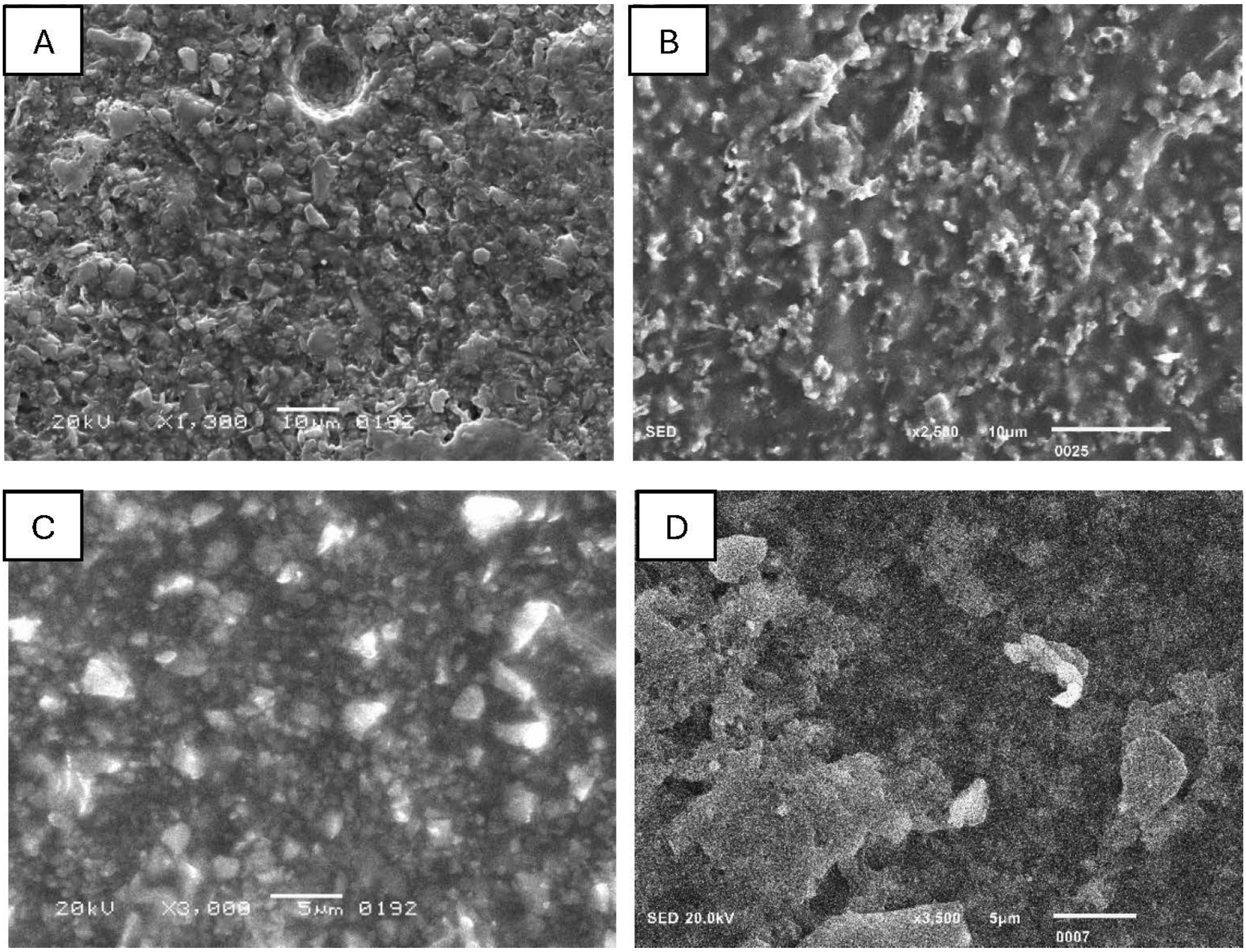

Fig. 1: SEM micrograph A) LDC treated with Er Yag laser demonstrates loss of matrix with prominent visible glass particles. B) RBC treated with Er: YAG laser shows fusion of particles with melting of resin, improving *Ra*. SEM image C) Shows LDC treated with RD-LLLT, no loss of inter-glass matrix. Glass particles are not prominent. D) RBC treated with RD-LLLT shows no matrix loss, with particle-reinforced composite visible.

Table 1: Contact angle measurements in degrees on LDC and RBC conditioned according to different conditioning regimes.

Conditioning regime	Mean ± SD	p-value %
Group 1A: HFA+ LDC	8.77 ± 0.28[a]	<0.05
Group 1B: HFA+RBC	20.43 ± 0.10[b]	
Group 2A: Er: YAG laser + LDC	8.99 ± 0.26[a]	
Group 2B: Er: YAG laser + RBC	9.12 ± 0.30[a]	
Group 3A: LLLT (RD)+ LDC	37.21 ± 0.32[c]	
Group 3B: LLLT (RD)+RBC	38.39 ± 0.36[c]	

% ANOVA
Hydrofluoric acid (HFA), Erbium-doped yttrium aluminum garnet (Er: YAG) laser, Low-level laser therapy, Radachlorin
Different superscript lower-case letters denote statistically significant differences within the same column (p<0.05)

(3) SBS assessment

The mean SBS of LDC and RBC bonded to resin cements after using different surface conditioners are presented in Table 2. The lowest SBS was identified in Group 3B (LLLT (RD) + RBC) (8.11 ± 0.87 MPa). Whereas the highest bond integrity was displayed by Group 1A (HFA + LDC) (12.98 ± 1.23 MPa) samples. Comparison among different investigated groups revealed that Group 1A, Group 2A (Er: YAG laser + LDC) (12.87 ± 1.05 MPa), and Group 2B (Er: YAG laser + RBC) (12.59 ± 0.93 MPa) demonstrated comparable SBS outcomes. ($p > 0.05$) Likewise, Group 3A (LLLT (RD) + LDC) (8.23 ± 0.76 MPa) and Group 3B also revealed no significant difference in their bond scores ($p > 0.05$). On the contrary, Group 1B (HFA + RBC) (9.65 ± 0.98) displayed significantly different bond integrity of resin cement from other tested groups ($p < 0.05$).

(4) Fracture pattern analysis

Fracture patterns after debonding are shown in Fig. 2. It was observed that LDC and RBC discs preconditioned with the Er: YAG laser and LDC discs conditioned with HFA demonstrated predominantly cohesive fracture. Whereas RBC treated with HFA presented admixed failure. LLLT-conditioned RBC and LDC discs, on the other hand, exhibited mostly adhesive failures.

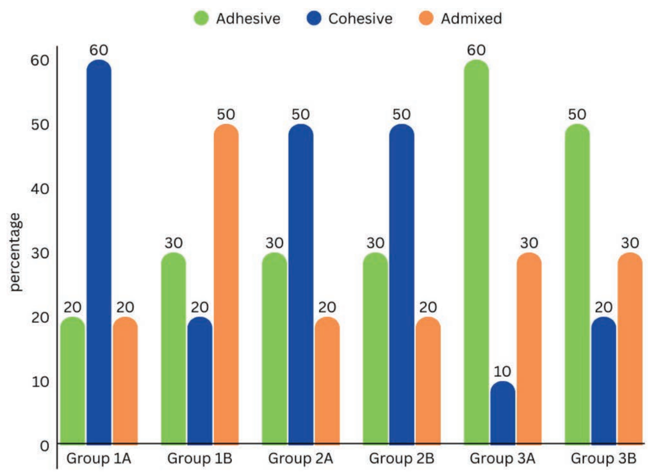

Fig. 2: Fracture distribution among the different tested groups.

Table 2: SBS of LDC and RBC bonded to resin cements after conditioning according to different protocols.

Conditioning regime	Mean ± SD MPa	p- value%
Group 1A: HFA+ LDC	12.98 ± 1.23[a]	<0.05
Group 1B: HFA+RBC	9.65 ± 0.98[b]	
Group 2A: Er: YAG laser + LDC	12.87 ± 1.05[a]	
Group 2B: Er: YAG laser + RBC	12.59 ± 0.93[a]	
Group 3A: LLLT (RD)+ LDC	8.23 ± 0.76[c]	
Group 3A: LLLT (RD)+ RBC	8.11 ± 0.87[c]	

% ANOVA
Hydrofluoric acid (HFA), Erbium-doped yttrium aluminum garnet (Er: YAG) laser, Low-level laser therapy, Radachlorin
Different superscript lower-case letters denote statistically significant differences within the same column (p<0.05)

IV. Discussion

The current inquiry was founded on the assumption that there will not be a notable difference in the CA and SBS of RD-LLLT- and Er: YAG-laser-pretreated LDC and RBC discs in comparison to the HFA. Additionally, it was also expected that there would be no major disparity in the CA and bond integrity of resin cement to LDC and RBC across the same conditioning groups. Based on the findings, it can be stated that Er: YAG-laser-treated discs presented comparable scores of CA and SBS to those of HFA in LDC discs. However, it resulted in significantly lower CA and higher SBS than in the RBC group when compared to HFA. RD-LLLT-conditioned LDC and RBC samples presented significantly higher CA and lower SBS than HFA and Er: YAG laser groups, thus partially rejecting the primary null hypothesis. Whereas the second predicted assumption was partially rejected, as only HFA-treated LDC and RBC discs displayed significantly different CA and SBS. In the present study, the authors opted to evaluate the SBS test due to its established reputation as the most straightforward and expedient assessment that facilitates uniform stress distribution throughout the loading process, thereby yielding more reliable outcomes [6,26].

The measurement of the CA is essential for comprehending the extent to which a liquid will effectively wet a ceramic surface subsequent to conditioning. Surface conditioners modify the surface energy and roughness of the ceramic material, thereby affecting its wettability and ultimately influencing the adhesion of resin cement [27]. Based on the findings, it was observed that the pretreatment of LDC and RBC discs with HFA resulted in significantly different CA and SBS. A past study unveiled that the utilization of 9.5 % HFA for one minute on hybrid ceramics yielded superior bond integrity in comparison with alternative treatment modalities [28]. Furthermore, Mandil and colleagues reported that there is no significant difference in the SBS outcomes when LDC and RBC are conditioned with HFA [29]. However, based on the results, authors of the existing study stated that since HFA selectively dissolves the glassy matrix in LDC, which results in the creation of a rough surface, hence ultimately increasing the bond strength of resin cement through micromechanical retention [30]. RBC, on the other hand, contains a higher proportion of resin matrix, which may not respond as effectively to HFA etching and therefore results in significantly higher CA and lower SBS than LDC discs [31]. Nevertheless, additional investigations are essential to validate the discoveries of the present examination.

Likewise, Er: YAG-laser-pretreated discs presented comparable scores of Ca and SBS in the LDC and RBC group. However, there is a scarcity of comparative studies that have identified the role of Er: YAG laser on LDC and RBC. According to the available evidence, an *in vitro* analysis by Dilber *et al.* reported that Er: YAG laser irradiation results in greater surface roughness compared to HFA etching on LDC [32]. Similarly, Ozdemir and coworkers concurred that Er: YAG laser irradiation on LDC enhances the SBS values and could serve as an alternative to HFA [32]. Similarly, a lab-based analysis by Celiksoz and coauthors discovered that Er: YAG lasers have been considered as an alternative to other surface pretreatments for composite repair of RBC [33]. The findings of the present analysis can be explained by the fact that Er: YAG lasers have the potential to enhance the adhesion of resin cements by augmenting the surface roughness of ceramics via a photothermal mechanism that induces material removal and induces surface irregularities [34,35]. This mechanism encompasses the conversion of the laser's energy into thermal energy, which may result in ablation (vaporization) or the melting of the ceramic substrate, thereby producing a more textured surface profile [36]. Nevertheless, the effectiveness of this process is contingent upon the optimal parameters (e.g. power, pulse duration, frequency) as well as the particular type of ceramic material used [37–39].

Regarding RD-LLLT, it was observed that in both groups there were higher CA and lower SBS. These outcomes were comparable to each other yet significantly lower than those of the other tested groups. This is in agreement with the outcomes of a lab-based investigation conducted by Alshahrani and associates. They reported that RD-mediated photodynamic therapy, when used to condition glass fiber post, does not increase the surface roughness and bond strength as there was no fiber exposure and the resin matrix extended over the entire length of the post [40].

Regarding the fracture pattern, it was observed that LDC and RBC discs preconditioned with Er: YAG laser and LDC-treated discs conditioned with HFA predominantly demonstrated cohesive fractures. Whereas RBC-treated samples with HFA presented admixed failure. LLLT-conditioned RBC and LDC discs exhibited mostly adhesive failures. The failure modes justify the bond integrity outcomes. Studies have demonstrated that cohesive failure predominantly arises from the failure of interactions among adhesive molecules as opposed to occurring at the adhesive-substrate interface [41,42]. However, adhesive failures are mostly due to the inherent characteristics of the adhesive substance and extrinsic factors such as the oral milieu, which substantially affect the efficacy of adhesive performance.

The ongoing study uncovered various intrinsic limitations. Initially, this research was conducted in a controlled laboratory environment, and any findings from the results must be discerned carefully when applied clinically. Moreover, the lack of surface characterization methods such as Raman spectroscopy and X-ray photoelectron spectroscopy could impede a deeper understanding. Furthermore, the present analysis used only one type of resin cement and only one concentration of surface conditioners, which may make the findings applicable solely to that brand and concentrations used.

V. Conclusions

The Er: YAG laser can be considered as a suitable alternative to hydrofluoric acid in enhancing the contact angle and bond integrity of adhesive cement. LDC and RBC exhibited comparable contact angle and bond strength outcomes except in the hydrofluoric acid groups.

References

1 Blatz, M.B., Conejo, J.: The current state of chairside digital dentistry and materials, *Dent. Clin. North. Am.*, **63**, [2], 175–197, (2019).

2 Zicari, F., De Munck, J., Scotti, R., Naert, I., Van Meerbeek, B.: Factors affecting the cement-post interface, *Dent. Mater.*, **28**, 287–297, (2012).

3 Alrahlah, A., Awad, M.M., Vohra, F., Al-Mudahi, A., Al jeaidi, Z.A., Elsharawy, M.: Effect of self-etching ceramic primer and universal adhesive on bond strength of lithium disilicate ceramic, *J. Adhes. Sci. Technol.*, **31**, 2611–2619, (2017).

4 AlShahrani, I., Kamran, M.A., Almoammar, S., Alhaizaey, A.: Photosensitization of lithium di-silicate ceramic by er, Cr: YSGG and fractional carbon dioxide laser bonded to orthodontic bracket, *Photodiagnosis Photodyn. Ther.*, **28**, 273–276, (2019).

5 Alhamdan, E.M.: Repair bond strength and surface roughness of zirconia ceramics treated via carbon dioxide laser, malachite green, and Sandblasting. A lab-based study, *J. Ceram. Sci. Technol.*, **16**, 85–92, (2025).

6 Maawadh, A.M., Almohareb, T., Al-Hamdan, R.S., Al Deeb, M., Naseem, M., Alhenaki, A.M., Vohra, F., Abduljabbar, T.: Repair strength and surface topography of lithium disilicate and hybrid resin ceramics with LLLT and photodynamic therapy in comparison to hydrofluoric acid, *J. Appl. Biomater. Funct. Mater.*, **18**, 6938–6943, (2020). doi: https://doi.org/10.1177/2280800020966938.

7 Jorquera, G., Mahn, E., Sanchez, J.P., Berrera, S., Prado, M.J., Stange, V.B.: Hybrid ceramics in Dentistry: A literature review, *J. Clin. Res. Dent.*, **1**, 1–5 (2018).

8 Albakri, A.S.: Pretreatment of hybrid ceramics using alumina (Al_2O_3) nanoparticles, hydrofluoric acid, and Holmium: YAG laser for optimizing surface roughness, shear bond strength, and topography, *J. Biomater. Tissue Eng.*, **13**, 1133–1138, (2023).

9 Jung, S.N., Rüttermann, S.: Influence of mechanical and chemical pre-treatments on the repair of a hybrid ceramic, *Dent. Mater.*, **38**, 1140–1148, (2022).

10 Poosti, M., Jahanbin, A., Mahdavi, P., Mehrnoush, S.: Porcelain conditioning with Nd:YAG and Er:YAG laser for bracket bonding in orthodontics, *Lasers Med. Sci.*, **27**, 321–324, (2021).

11 Amaral, R., Ozcan, M., Bottino, M.A., Valandro, L.F.: Resin bonding to a feldspar ceramic after different ceramic surface conditioning methods: evaluation of contact angle, surface pH, and microtensile bond strength durability, *J. Adhes. Dent.*, **13**, 551–560, (2011).

12 Aljamhan, A., Alkhudhairy, F.: Impact of hydrofluoric acid, ytterbium fiber lasers, and hydroxyapatite nanoparticles on surface roughness and bonding strength of resin cement with different viscosities to lithium disilicate glass Ceramic: SEM and EDX analysis, *Crystals*, **15**, 661–668, (2025).

13 Ozge, C., Yilmaz, N.A., Balin, E.: Effect of Er: yag laser on repair bond strength of a nano hybrid composite, *J. Stomatol.*, **75**, 122–129, (2022).

14 Türker, N., Büyükkaplan, U.Ş., Başar, E.K., Özarslan, M.M.: The effects of different surface treatments on the shear bond strengths of two dual-cure resin cements to CAD/CAM restorative materials, *J. Adv. Prosthodont.*, **12**, 189–196, (2020).

15 Almutairi, B., Al-Qahtani, A.S., Shabbir, T., Leemani, M.J., Unar, J., Manzar, N., Abduljabbar, T.: A surface topographical analysis of lithium disilicate ceramics pretreated with rose bengal, Er: YAG laser, and ceramic primer on bond integrity, surface roughness, and bond failure to composite resin, *Sci. Adv. Mater.*, **16**, 800–806, (2024).

16 Douillard, S., Olivier, D., Patrice, T.: *In vitro* and *in vivo* evaluation of Radachlorin® sensitizer for photodynamic therapy, *Photochem. Photobiol. Sci.*, **8**, 405–413, (2009).

17 Moslemi, N., Rouzmeh, N., Shakerinia, F., Bahador, A., Azar, P.S., Kharazifard, M.J., Paknejad, M., Fekrazad, R.: Photodynamic inactivation of porphyromonas gingivalis utilizing radachlorin and toluidine blue O as photosensitizers: an *in vitro* study, *J. Lasers Med. Sci.*, **9**, 107–112, (2018).

18 Alanazi, A.M., Khan, N.A., Khan, A.A., Ansari, Z., Shabbir, T., Leemani, M.J.: Lithium disilicate ceramics surface treatment using low level laser therapy activated riboflavin, and Ti: Al_2O_3 laser on the colour change, surface roughness, and shear bond strength to adhesive cement: an *in vitro* SEM valuation, *Ceram – Silikaty*, **69**, [1], 93–100, (2025).

19 Moura, D.M.D., de Araújo, A.M.M., de Souza, K.B., Veríssimo, A.H., Tribst, J.P.M., de Assunção e Souza, R.O.: Hydrofluoric acid concentration, time, and use of phosphoric acid on the bond strength of feldspathic ceramics, *Braz. Oral Res.*, **34**, (2024). doi: https://doi.org/10.1590/1807-3107bor-2020.vol34.0018.

20 Gorler, O., Dogan, D.O., Ulgey, M., Goze, A., Hubbezoğlu, I., Zan, R., Ozdemir, A.K.: The effects of Er: YAG, Nd: YAG, and Ho: YAG laser surface treatments to acrylic resin denture bases on the tensile bond strength of silicone-based resilient liners, *Photomed. Laser Surg.*, **33**, 409–414, (2015).

21 Benetti, P., Della Bona, A., Kelly, J.R.: Evaluation of thermal compatibility between core and veneer dental ceramics using shear bond strength test and contact angle measurement, *Dent. Mater.*, **26**, 743–750, (2010). doi: https://doi.org/10.1016/j.dental.2010.03.019.

22 Alsunbul, H., Almutairi, B., Aljanakh, M., Abduljabbar, T.: Hybrid ceramic repair strength, surface roughness, and bond failure, using methylene blue-activated low-level laser therapy, carbon dioxide, and Ti: Al_2O_3 laser, *Photodiagnosis Photodyn. Ther.*, **43**, 693–700, (2023). doi: https://doi.org/10.1016/j.pdpdt.2023.103693.

23 Alkhudhairy, F., Shono, N.N.: An investigation of Y-TZP surface characteristics and adhesive properties following treatment with tri-biochemical silica coating, femtosecond laser, and nano-hydroxyapatite: A scanning electron microscopy evaluation, *Pak. J. Med. Sci.*, **41**, 758–762, (2025). doi: https://doi.org/10.12669/pjms.41.3.11302.

24 Aljamhan, A., Alkhudhairy, F.: Topographic modification of semi-crystalline thermoplastic polyetheretherketone using argon plasma and femtosecond laser: A lab-based evaluation, *Pak. J. Med. Sci.*, **41**, 1980–1985, (2025). doi: https://doi.org/10.12669/pjms.41.7.12185.

25 Aljamhan, A.S., Alrefeai, M.H., Alhabdan, A., Alzehiri, M.H., Naseem, M., Vohra, F., Alkhudhairy, F.: Interaction of zirconium oxide nanoparticle infiltrated resin adhesive with dentin conditioned by phosphoric acid and er, Cr:YSGG laser, *J. Appl. Biomater. Funct. Mater.*, **20**, 7349–7455, (2020). doi: https://doi.org/10.1177/22808000221087349.

26 Karadas, M., Cantekin, K., Gumus, H., Ateş, S.M., Duymuş, Z.Y.: Evaluation of the bond strength of different adhesive agents to a resin-modified calcium silicate material, *Scanning*, **38**, 403–411, (2024). doi: https://doi.org/10.1002/sca.21284.

27 Oliveira, L.T., De Castro, E.F., Azevedo, V.L.B., De Andrade, O.S., Faraoni, J.J., Palma-Dibb, R.G., Dias, C.T.S., Giannini, M.: Effect of ceramic conditioners on surface morphology, roughness, contact angle, adhesion, microstructure, and composition of CAD/CAM ceramics, *Oper. Dent.*, **48**, 277–293, (2023). doi: https://doi.org/10.2341/21-078-L.

28 Motevasselian, F., Amiri, Z., Chiniforush, N., Mirzaei, M., Thompson, V.: *In vitro* evaluation of the effect of different surface treatments of a hybrid ceramic on the microtensile bond strength to a luting resin cement, *J. Lasers Med. Sci.*, **10**, 297–303, (2013). doi: https://doi.org/10.15171/jlms.2019.48.

[29] Mandil, S.T., Katamish, H., Salah, T.: Effect of surface treatment of two ceramic materials by er, Cr: YSGG laser irradiation on the shear bond strength to resin cement: a comparative *in-vitro* study, *Brazilian Dent. Sci.*, **23**, 1 – 12, (2020).
doi: https://doi.org/10.14295/bds.2020.v23i3.1950.

[30] Levartovsky, S., Bohbot, H., Shem-Tov, K., Brosh, T., Pilo, R.: Effect of different surface treatments of lithium disilicate on the adhesive properties of resin cements, *Materials*, **14**, [12], 547 – 553, (2021). doi: https://doi.org/10.3390/ma14123302.

[31] Dikicier, S., Korkmaz, C., Atay, A.: Surface roughness and characteristics of CAD/CAM zirconia and glass ceramics after combined treatment procedures, *BMC Oral Health*, **23**, 22 [1], 524 – 529, (2022)

[32] Dilber, E., Yavuz, T., Kara, H.B., Ozturk, A.N.: Comparison of the effects of surface treatments on roughness of two ceramic systems, *Photomed. Laser Surg.*, **30**, [6], 308 – 314, (2012).
doi: https://doi.org/10.1089/pho.2011.3153.

[33] Ozge, C., Yilmaz, N.A., Balin, E.: Effect of Er:Yag laser on repair bond strength of a nano hybrid composite, *J. Stomatol.*, **75**, [2], 122 – 129, (2022).

[34] Mirhashemi, A.H., Chiniforush, N., Sharifi, N., Hosseini, A.M.: Comparative efficacy of er,Cr: YSGG and Er: YAG lasers for etching of composite for orthodontic bracket bonding, *Lasers Med. Sci.*, **33**, [4], 835 – 841, (2018).
doi: https://doi.org/10.1007/s10103-017-2417-1.

[35] Almohareb, T., Al Ahdal,K., Maawadh, AM., Al Deeb, L., Alshamrani, AS., Alrahlah A.: Bleached enamel reversal using grape seed extract, green tea, curcumin-activated photodynamic therapy, and Er:YAG on microleakage and bond integrity of composite material bonded to the enamel surface, *Photodiagnosis Photodyn. Ther.*, **45**,103939 – 103943, (2024).

[36] Emam, A.N.M., Bahra, S. El., Alqhtani, M.A., Alsuwayyigh, N., Almutairi, H.K., Alaqeel, N., Albalawi, M., Barakat, A., Samran, A., Niazi, F.H.: *In-Vitro* SEM-EDX analysis of surface roughness, shear bond strength, and color change in polymer-infiltrated ceramic treated with rose bengal activated by low-level laser therapy, non-thermal plasma, and Er: YAG laser, *J. Biomater. Tissue Eng.*, **14**, [3],137 – 144, (2024).
doi: https://doi.org/10.1166/jbt.2024.3368.

[37] Alkhudhairy, F., Naseem, M., Ahmad, ZH., Alnooh, AN., Vohra, F.: Influence of photobio-modulation with an er,Cr: YSGG laser on dentin adhesion bonded with bioactive and resin-modified glass ionomer cement, *J. Appl. Biomater. Funct. Mater.*, **17**, [4], 691 – 699, (2019).
doi: https://doi.org/10.1177/2280800019880691.

[38] Vohra, F., Labban, N., Al-Hussaini, A., Al-Jarboua, M., Zawawi, R., Alrahlah, A., Naseem M.: Influence of Er;Cr: YSGG laser on shear bond strength and color stability of lithium disilicate Ceramics: an *in Vitro* study, *Photobiomodul. Photomed., Laser Surg.*, **37**, [8], 483 – 488 (2019).

[39] Alkhudhairy, F., Vohra, F., Naseem, M., Owais, M.M., Amer, A.H.B., Almutairi, K.B.: Color stability and degree of conversion of a novel dibenzoyl germanium derivative containing photo-polymerized resin luting cement, *J. Appl. Biomater. Funct. Mater.*, **18**, 7487 – 7495, (2020).

[40] Alshahrani, A.: Post surface conditioning via air abrasion, Nd: YAG laser and radachlorin activated photodynamic therapy on surface roughness, surface topography, and bond strength to root dentin, *Photodiagnosis Photodyn. Ther.*, **54**. 8581 – 8589, (2025).

[41] Alrahlah, A., Naseem, M., Tanveer, SA., Abrar, E., Charania, A., AlRifaiy, MQ., Vohra, F.: Influence of disinfection of caries effected dentin with different concentration of silver diamine fluoride, curcumin and er, Cr: YSGG on adhesive bond strength to resin composite, *Photodiagnosis Photodyn. Ther.*, **32**, 4788 – 4795, (2024).
doi: https://doi.org/10.1016/j.pdpdt.2020.102065.

[42] Al Deeb, L., Bin-Shuwaish, MS., Abrar, E., Naseem, M., Al-Hamdan, RS., Maawadh, AM., Al Deeb, M., Almohareb, T., Al Ahdal, K., Vohra, F., Abduljabbar, T.: Efficacy of chlorhexidine, er cr YSGG laser and photodynamic therapy on the adhesive bond integrity of caries affected dentin. an *in-vitro* study, *Photodiagnosis Photodyn. Ther.*, **31**, 103571 – 103579, (2020).
doi: https://doi.org/10.1016/j.pdpdt.2020.101875.